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(54) Abstract Title
Controlling airflow in an internal combustion engine with air assist fuel injectors

(57) An air control method for an internal combustion engine having air assist injectors (66) and an electronically controlled throttle (58,62,63,64) maximises airflow through the injectors (66) while maintaining a range of authority for the electronically controlled throttle. This method maximizes the benefits of fuel atomization while maintaining a desired engine speed in the presence of disturbances.

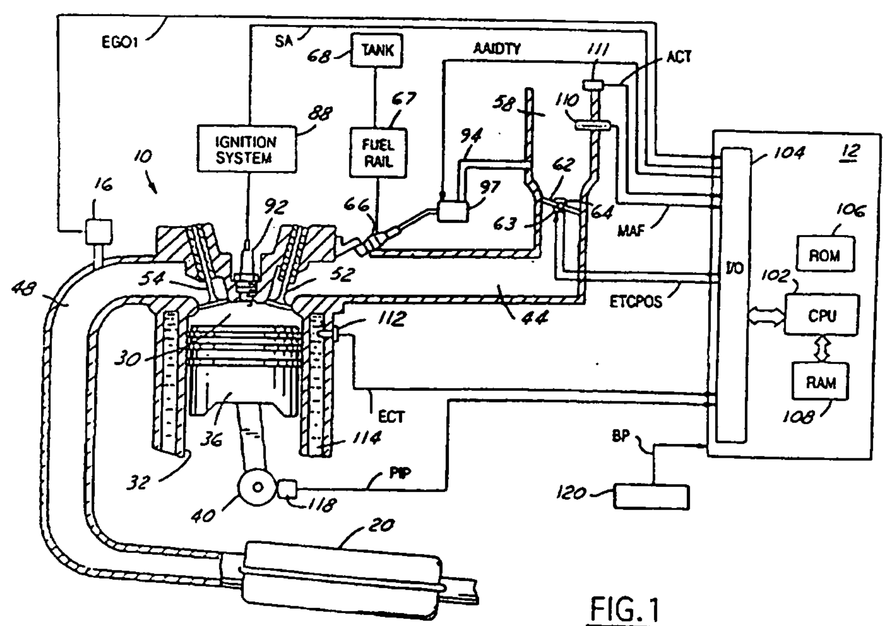


FIG. 1

GB 2 338 085 A

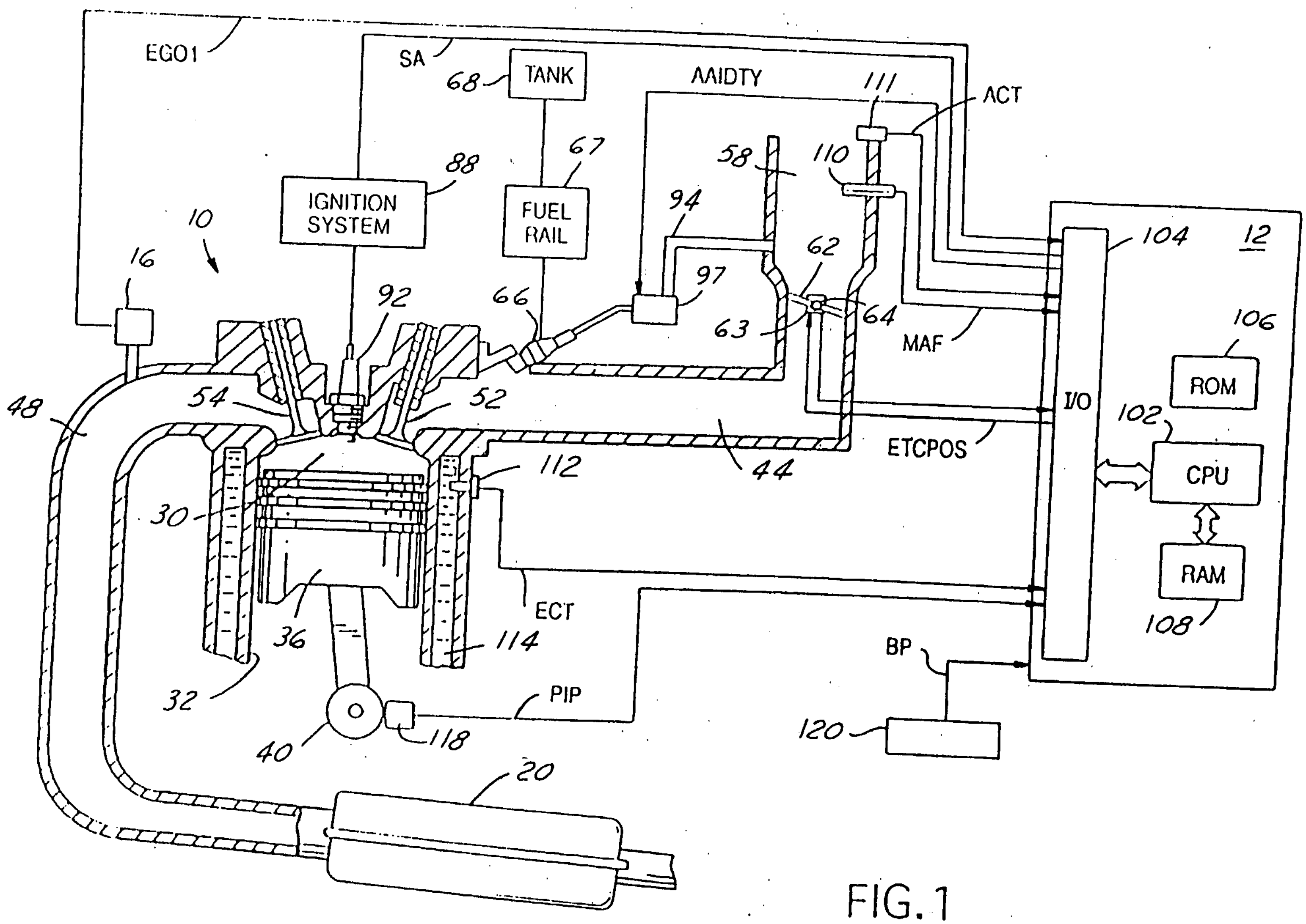
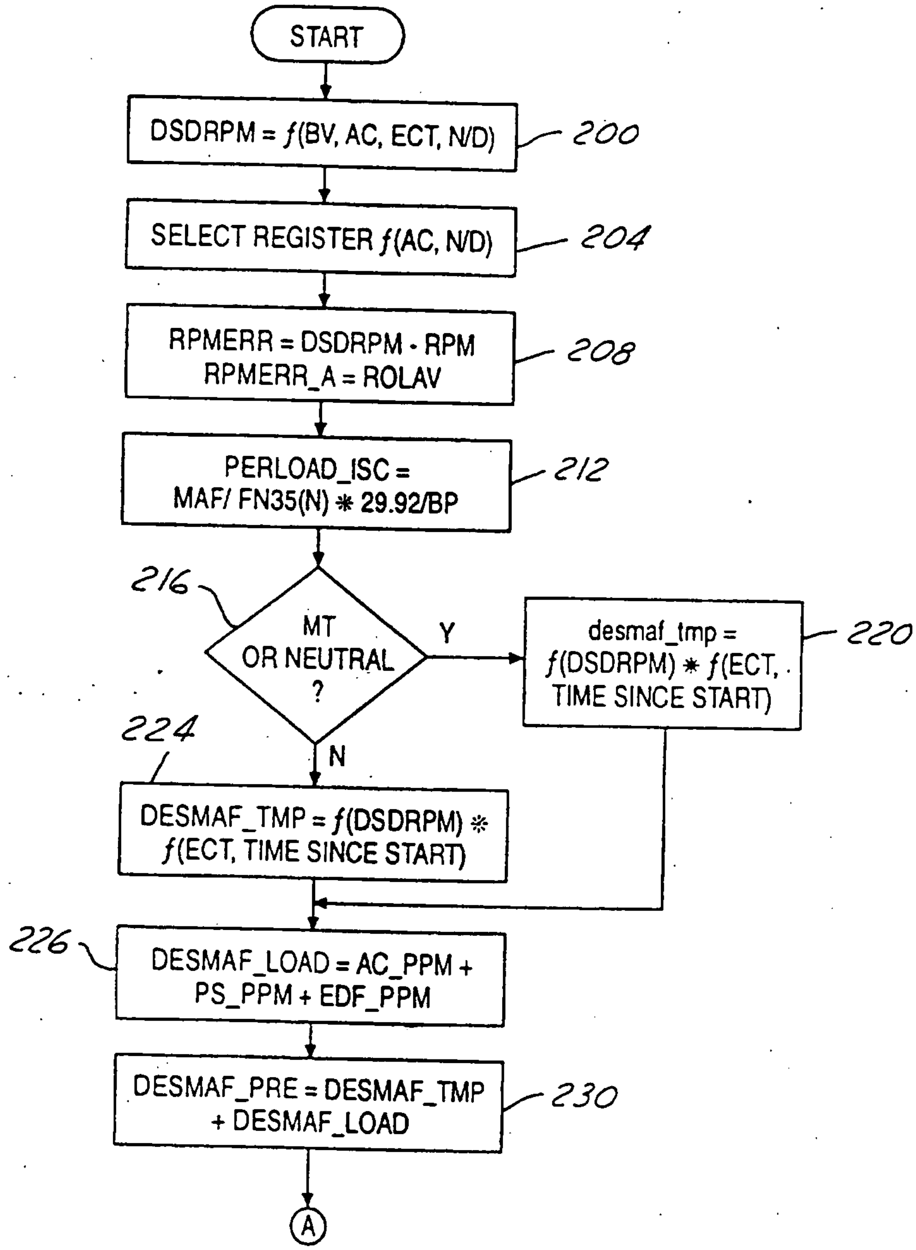

EGO1
SA
68
TANK
AAIDTY
111
ACT
88
67
IGNITION SYSTEM
FUEL RAIL
58
110
10
16
94
62
104
12
97
92
66
63
64
MAF
106
ROM
48
54
52
I/O
102
ETCPOS
112
44
CPU
30
RAM
ECT
36
114
108
BP
32
PIP
40
118
120
20

FIG.1



START
DSDRPM = ƒ(BV, AC, ECT, N/D)
200
SELECT REGISTER ƒ(AC, N/D)
204
RPMERR = DSDRPM - RPM
RPMERR_A = ROLAV
208
PERLOAD_ISC =
MAF/ FN35(N) * 29.92/BP
212
216
MT
OR NEUTRAL
?
Y
desmaf_tmp =
ƒ(DSDRPM) * ƒ(ECT,
TIME SINCE START)
220
224
N
DESMAF_TMP = ƒ(DSDRPM) *
ƒ(ECT, TIME SINCE START)
226
DESMAF_LOAD = AC_PPM +
PS_PPM + EDF_PPM
DESMAF_PRE = DESMAF_TMP
+ DESMAF_LOAD
230
A

FIG.2A

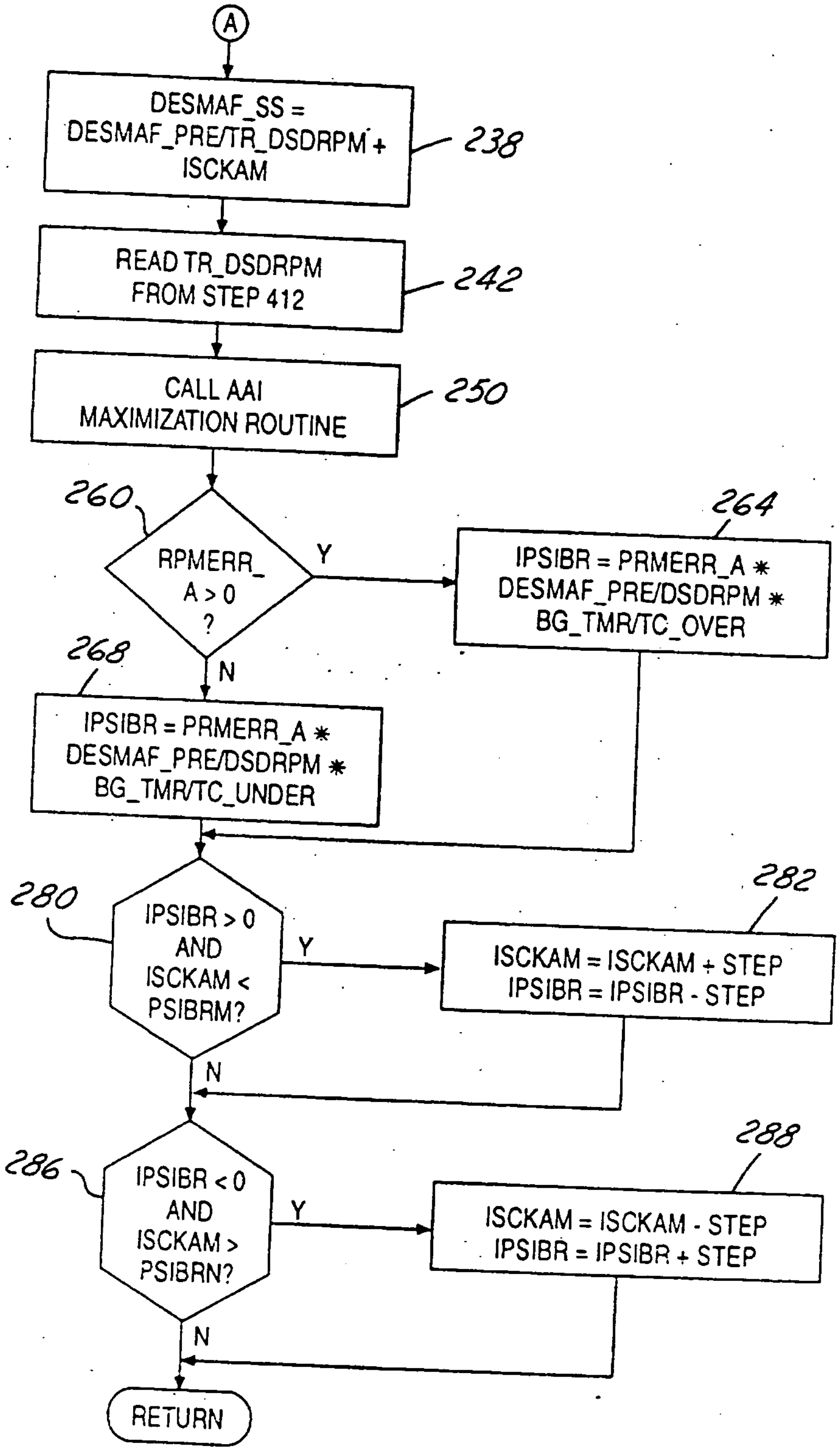

A
DESMAF_SS = DESMAF_PRE/TR_DSDRPM + ISCKAM
238
READ TR_DSDRPM FROM STEP 412
242
CALL AAI MAXIMIZATION ROUTINE
250
260
RPMERR_ A > 0 ?
Y
264
IPSIBR = PRMERR_A * DESMAF_PRE/DSDRPM * BG_TMR/TC_OVER
268
N
IPSIBR = PRMERR_A * DESMAF_PRE/DSDRPM * BG_TMR/TC_UNDER
280
IPSIBR > 0 AND ISCKAM < PSIBRM?
Y
282
ISCKAM = ISCKAM + STEP
IPSIBR = IPSIBR - STEP
N
286
IPSIBR < 0 AND ISCKAM > PSIBRN?
Y
288
ISCKAM = ISCKAM - STEP
IPSIBR = IPSIBR + STEP
N
RETURN

FIG. 2B

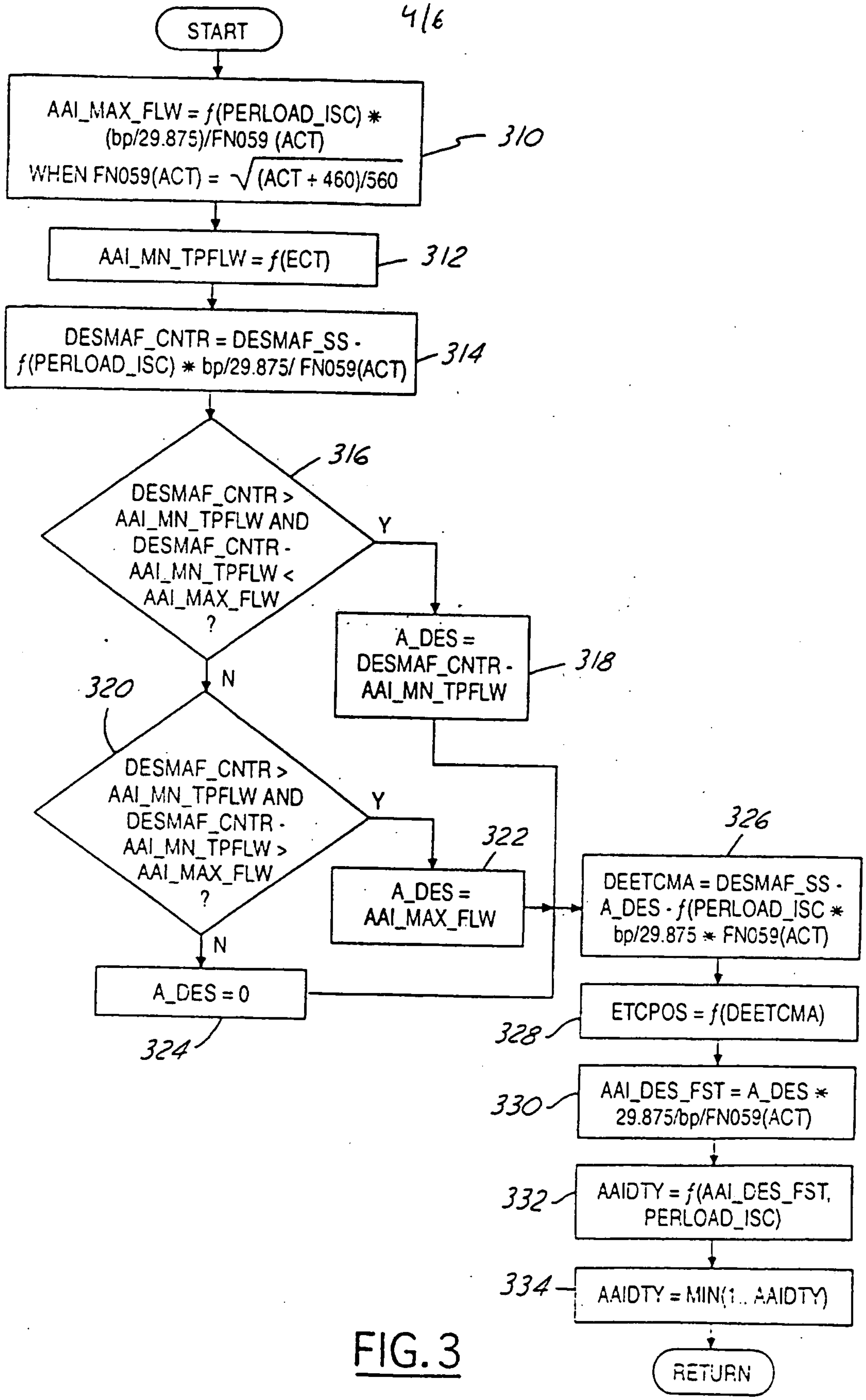

START
AAI_MAX_FLW = f(PERLOAD_ISC) * (bp/29.875)/FN059 (ACT)
WHEN FN059(ACT) = √(ACT + 460)/560
310
AAI_MN_TPFLW = f(ECT)
312
DESMAF_CNTR = DESMAF_SS - f(PERLOAD_ISC) * bp/29.875/ FN059(ACT)
314
316
DESMAF_CNTR > AAI_MN_TPFLW AND DESMAF_CNTR - AAI_MN_TPFLW < AAI_MAX_FLW ?
Y
N
A_DES = DESMAF_CNTR - AAI_MN_TPFLW
318
320
DESMAF_CNTR > AAI_MN_TPFLW AND DESMAF_CNTR - AAI_MN_TPFLW > AAI_MAX_FLW ?
Y
N
322
A_DES = AAI_MAX_FLW
326
DEETCMA = DESMAF_SS - A_DES - f(PERLOAD_ISC * bp/29.875 * FN059(ACT)
A_DES = 0
324
ETCPOS = f(DEETCMA)
328
AAI_DES_FST = A_DES * 29.875/bp/FN059(ACT)
330
AAIDTY = f(AAI_DES_FST, PERLOAD_ISC)
332
AAIDTY = MIN(1., AAIDTY)
334
RETURN

FIG. 3

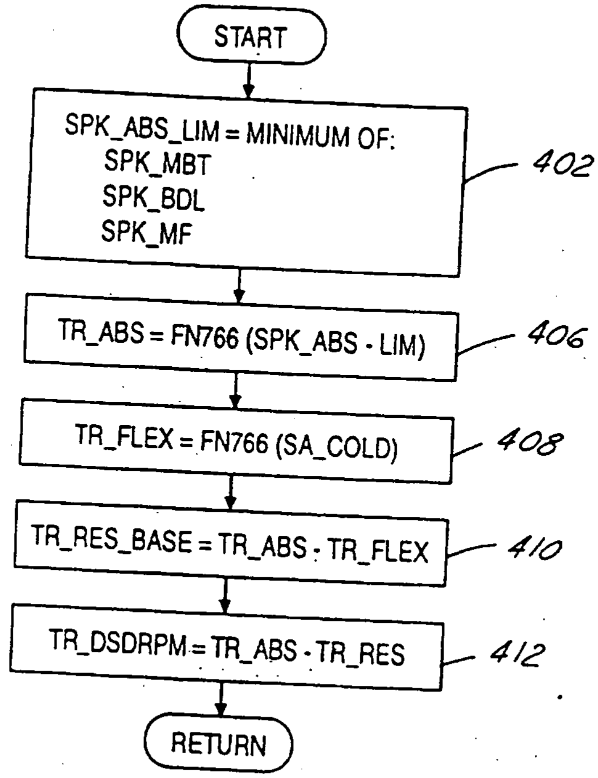

START
SPK_ABS_LIM = MINIMUM OF:
SPK_MBT
SPK_BDL
SPK_MF
402
TR_ABS = FN766 (SPK_ABS - LIM)
406
TR_FLEX = FN766 (SA_COLD)
408
TR_RES_BASE = TR_ABS - TR_FLEX
410
TR_DSDRPM = TR_ABS - TR_RES
412
RETURN

FIG. 4

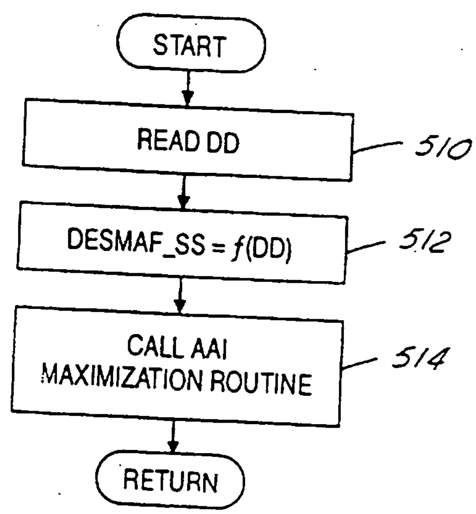

START
READ DD
510
DESMAF_SS = f(DD)
512
CALL AAI
MAXIMIZATION ROUTINE
514
RETURN

FIG. 5

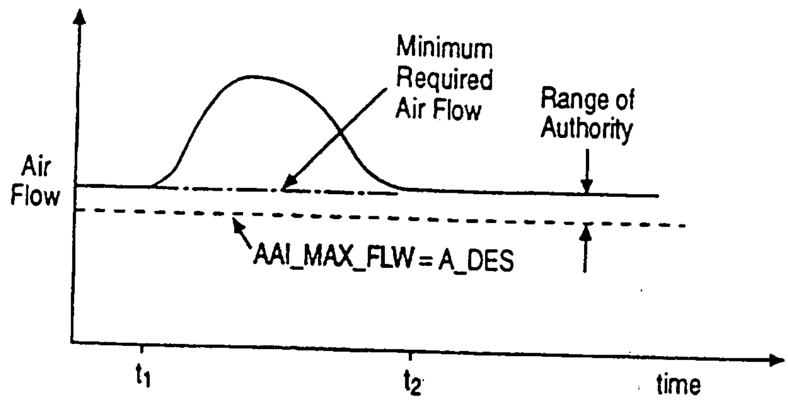

Minimum
Required
Air Flow
Range of
Authority
Air
Flow
AAI_MAX_FLW = A_DES
t_1
t_2
time

FIG. 6

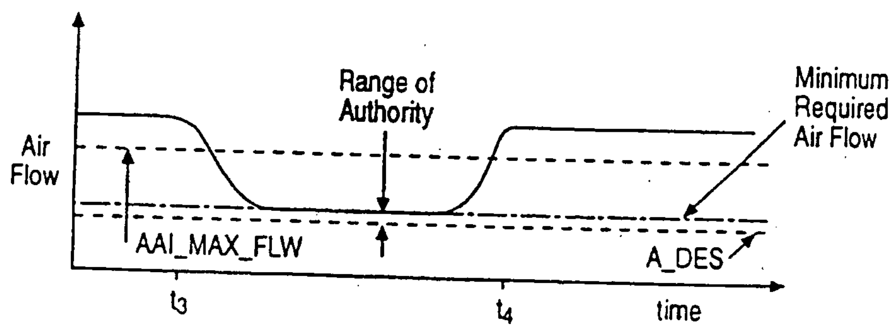

Range of
Authority
Minimum
Required
Air Flow
Air
Flow
AAI_MAX_FLW
A_DES
t_3
t_4
time

FIG. 7

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AIR CONTROL SYSTEM

The present invention relates to air control systems for internal combustion engines.

Internal combustion engines use fuel injectors to precisely control the amount of fuel inducted into the engine's cylinders. Also, fuel injectors atomize the liquid fuel, increasing the homogeneity of the air and fuel mixture. Air assist injectors are devices that use airflow to enhance the atomization of fuel injected into an engine's cylinder. Air assist injectors may be required on some vehicles where additional fuel vaporization can promote better combustion and lower regulated emissions. Further, the air flowing through the air assist injector can be controlled to maximize the benefit as a function of engine operating conditions.

For example, at low engine operating temperature, fuel atomization can be enhanced by controlling a flow valve to be substantially open, thereby allowing a large airflow through the air assist injectors. On the other hand, air assist injector airflow can be restricted by controlling the flow valve to be substantially closed as the temperature increases to prevent overrunning of the engine. Another example, which can be combined with the previous example, is that the flow valve can be controlled to open proportionally to an engine load, thereby allowing an increasing airflow through the air assist injectors as engine load increases to counteract the decreasing pressure ratio caused by increasing manifold pressure. Such a system is disclosed in U.S. Patent 5,460,148.

The inventor herein has recognized numerous disadvantages with the above approaches. For example, when the engine is operating at a mid-load condition, the airflow through the air assist injectors will not be maximized because the flow valve will be partially restricting the airflow to the air assist injectors. This is due to the valve being open proportionally to engine load. In other

words, at mid-load, the valve is not fully open. Further, when the engine is started at a warm temperature, the flow valve will be restricting the airflow, thus preventing optimal atomization of the injected fuel, which can cause less than optimal emission control. Another disadvantage is related to the reliance on the operating temperature of the engine. For example, as an engine ages, less torque, and thus less air, may be required to maintain a given speed at a given temperature due to decreased friction. Thus, if temperature alone is used, the engine may develop an overrunning condition due to excess air flowing through the air assist injectors, which is utilized in combustion.

The present invention provides an air control method for an internal combustion engine, the engine having a first airflow control valve and air assist injectors. The method comprises the steps of calculating a minimum total required airflow based on engine operating conditions, controlling the first airflow control valve to regulate a first quantity of airflow through the engine, and controlling a second quantity of airflow through the air assist injectors such that said first quantity of airflow is greater than a predetermined value with said predetermined value being defined as a difference between said total required airflow and said first quantity, thereby allowing said first airflow control valve to maintain primary control of the engine.

The first airflow control valve is responsible for the instantaneous control of the engine. The second airflow control valve is responsible for providing a gradual adjustment of the airflow through the air assist injectors. By controlling the second airflow control valve such that the first airflow control valve is never fully closed, it is always possible to reject disturbances. This is particularly true when the first airflow control valve has a faster response and higher accuracy than the second airflow control valve. Also, this arrangement allows the second airflow control valve to maximize the air assist injector

airflow while maintaining the first airflow control valve's ability to reject disturbances.

An advantage of the above aspect of the invention is that overrunning of the engine speed is avoided.

Another advantage of the above aspect of the invention is that the fuel atomization is maximized.

Yet another advantage of the above aspect of the invention is that regulated emissions are minimized.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of an engine incorporating air assist injectors according to the present invention;

Figures 2A, 2B, 3, 4 and 5 are flow charts of various operations performed by a portion of the embodiment shown in Figure 1; and

Figures 6-7 are examples of operation according to the present invention.

Internal combustion engine 10 comprising a plurality of cylinders, one cylinder of which is shown in Figure 1, is controlled by electronic engine controller 12. Engine 10 includes combustion chamber 30 and cylinder walls 32 with piston 36 positioned therein and connected to crankshaft 40. Combustion chamber 30 is shown communicating with intake manifold 44 and exhaust manifold 48 via respective intake valve 52 and exhaust valve 54. Intake manifold 44 is shown communicating with throttle body 58 via throttle plate 62. Primary air control is governed by throttle plate 62. Throttle plate 62 is controlled by an electronic throttle controller 63. Throttle position of throttle plate 62 is measured by throttle position sensor 64. Controller 12 provides signal ETCPOS to electronic throttle controller 63 so that airflow is inducted into engine 10 around throttle plate 62 at a rate proportional to the signal ETCPOS. Intake manifold 44 is also shown having air assist injector 66 coupled thereto for delivering liquid fuel in proportion

to the pulse width of signal fpw from controller 12. Fuel is delivered to fuel injector 66 by a conventional fuel system including fuel tank 68, fuel pump (not shown), and fuel rail 67.

Conventional distributorless ignition system 88 provides ignition spark to combustion chamber 30 via spark plug 92 in response to spark advance signal SA from controller 12.

Catalytic type exhaust gas oxygen sensor 16 is shown coupled to exhaust manifold 48 upstream of catalytic converter 20. Sensor 16 provides signal EGO to controller 12 which converts signal EGO into a two-state signal. A high voltage state of converted signal EGO indicates exhaust gases are rich of a desired air/fuel ratio and a low voltage state of converted signal EGO indicates exhaust gases are lean of the desired air/fuel ratio. Typically, the desired air/fuel ratio is selected as stoichiometry which falls within the peak efficiency window of catalytic converter 20.

Bypass passageway 94 is shown coupled between throttle body 58 and air assist injector 66 via solenoid bypass valve 97. Controller 12 provides pulse width modulated signal AAIDTY to solenoid bypass valve 97 so that airflow is inducted into engine 10 at a rate proportional to the duty cycle of signal AAIDTY.

Controller 12 is shown in Figure 1 as a conventional microcomputer including: microprocessor unit 102, input/output ports 104, read only memory 106, random access memory 108, and a conventional data bus. Controller 12 is shown receiving various signals from sensors coupled to engine 10, in addition to those signals previously discussed, including: measurements of inducted mass air flow (MAF) from mass air flow sensor 110 coupled to throttle body 58; engine coolant temperature (ECT) from temperature sensor 112 coupled to cooling sleeve 114; intake air temperature (ACT) from temperature sensor 113 coupled to throttle body 58, a profile ignition pickup signal (PIP) from Hall effect sensor 118 coupled to crankshaft 40.

Referring now to Figures 2, 3, and 4, the subroutines executed by controller 12 for controlling engine idle speed are now described. Referring first to Figure 2, desired idle speed signal DSDRPM is first calculated as a function of battery voltage BV, air conditioner enable signal AC, engine coolant temperature ECT and the neutral or drive transmission signal N/D (step 200). One of four storage registers is selected in step 204 as a function of signal AC, and signal N/D. More specifically, the following registers are selected: a first register is selected if the transmission is not in drive and the air conditioner is on; a second register is selected if the air conditioner is off and the transmission is in drive; a third register is selected if the transmission is in neutral and the air conditioner is on; and a fourth register is selected if the transmission is in neutral and the air conditioner is off.

Idle speed error signal RPMERR is calculated in step 208 by subtracting an indication of engine speed signal rpm from desired idle speed signal DSDRPM. Signal RPMERR_A is also generated which is a rolling average of signal RPMERR with exponential smoothing. During step 212, an estimate of the pressure ratio across bypass valve 97 is provided. More specifically, signal PERLOAD_ISC is calculated by dividing a value (FN35) related to the peak air charge at wide open throttle into signal MAF. The resulting quotient is then multiplied by the ratio of 29.92 to barometric pressure BP.

If the vehicle has a manual transmission (MT) or an automatic transmission which is in neutral (step 216), desired air flow signal DESMAF_TMP is generated in step 220 as follows. A function of desired idle speed (DSDRPM) is multiplied times a function of engine coolant temperature (ECT) and time since engine start. On the other hand, if the answer to step 216 is negative, signal DESMAF_TMP is generated in step 224 as follows. A function of desired idle speed DSDRPM is multiplied by another function of engine coolant temperature (ECT) and the time since start.

Correction factor DESMAF_LOAD for desired mass air flow at various loads is generated during step 226. More specifically, signal DESMAF_LOAD is generated by summing three estimates of open loop airflow necessary to idle engine at a given speed, signal AC_PPM when the air conditioner is on, signal PS_PPM when power steering is employed, and signal EDF_PPM when a cooling fan is activated (step 226). Open loop prediction of desired air flow (signal DESMAF_PRE) is generated during step 230 by adding previously calculated signal DESMAF_TMP and signal DESMAF LOAD.

Open loop prediction of desired air flow (signal DESMAF PRE) is corrected by signal TR_DSDRPM which is generated from the subroutine described later herein with particular reference to Figure 4. In general, signal TR_DSDRPM provides a correction to the open loop desired air flow and corresponding open loop bypass throttle position of bypass valve 97. This correction preventing any initial drop in idle speed which would otherwise occur upon commencement of idle speed control under conditions when ignition timing is being retarded for rapid converter warm up.

Desired mass air flow DESMAF_SS is generated by adding signal ISCKAM, a learned adaptive integral term, to signal DESMAF_PRE and then dividing the sum by signal TR_DSDRPM. After TR_DSDRPM is read from the routine described later herein with particular reference to Figure 4 (step 242), the air assist injector maximization routine is called (step 250), which calculates the signals ETCPOS and AAIDTY as described later herein with particular reference to Figure 3.

If the rolling average of the engine speed error signal (RPMERR_A) is positive (step 260), then integral error term IPSIBR is generated as shown in the following equation:

IPSIBR = RPMERR_A * DESMAF_PRE/DSDRPM * BG_TMR/TC_OVER

where: BG_TMR is the background loop time; and TC_OVER is a calibratable time constant for overspeed.

On the other hand, when signal RPMERR_A is negative, the integral error term is calculated by the following equation:

IPSIBR = RPMERR_A * DESMAF_PRE/DSDRPM * BG_TMR/TC_UNDER

where: TC_UNDER is a calibratable time constant for underspeed.

When integration term IPSIBR is positive and adaptive air flow corrections ISCKAM are less than minimum clip value PSIBRN (step 280), air flow corrections ISCKAM and integral term IPSIBR are generated by the equations shown in Step 282 as follows:

ISCKAM = ISCKAM (previous) + STEP
IPSIBR = IPSIBR (previous) - STEP
where: STEP is a calibratable step size.

When integral term IPSIBR is negative and air flow correction term ISCKAM is greater than minimum clip PSIBRN (step 286), air flow correction terms ISCKAM and integral term IPSIBR are generated by the equations shown in Step 288 as follows:

ISCKAM = ISCKAM (previous) - STEP
IPSIBR = IPSIBR (previous) + STEP

Referring now to Figure 3, according to the present invention, a subroutine for controlling the distribution of air controlled by throttle plate 62 and bypass valve 97 is now described. Maximum airflow possible through the air assist flowpath (AAI_MAX_FLW) is calculated from a function of PERLOAD_ISC, barometric pressure BP, and ACT (step 310). Next, the minimum desired throttle mass flow to maintain an

idle speed control range of authority (AAI_MN_TPFLW) for electronic throttle controller 63 is calculated as a function engine coolant temperature (ECT) (step 312). The range of authority represents the amount of airflow necessary for the idle speed control system to reject disturbances. For example, it is undesirable for throttle plate 62 to be completely closed and all of the air necessary to create the desired torque being supplied through the air assist injectors. It is undesirable because if a load is suddenly removed, such as for example the air conditioning compressor, the engine will experience a rise in engine speed because bypass valve 97 cannot react quick enough. In step 314, the desired airflow around throttle plate 62 and air assist injector 66 (DESMAF_CNTR) is calculated by the equation shown in step 314 as follows:

DESMAF_CNTR = DESMAF_SS - FN818(PERLOAD_ISC)
*BP/29.875*FN059(ACT)

where: FN818(PERLOAD_ISC) is a function of PERLOAD_ISC and represents flow leaking into the manifold; and

FN059(ACT) = square root ((ACT+460)/560).

When, DESMAF_CNTR is greater than AAI_MN_TPFLW and DESMAF_CNTR-AAI_MN_TPFLW is less than AAI_MAX_FLW, the desired air assist airflow (A_DES) is set to DESMAF_CNTR-AAI_MN_TPFLW (steps 316 and 318). Otherwise, when DESMAF_CNTR is greater than AAI_MN_TPFLW and DESMAF_CNTR-AAI_MN_TPFLW is greater than AAI_MAX_FLW, the desired air assist airflow (A_DES) is set to AAI_MAX_FLW (steps 320 and 322). Otherwise, desired air assist airflow (A_DES) is set to zero (step 324).

Continuing with Figure 3, in step 326, the routine calculates the amount of air desired around throttle plate 62 as follows:

DEETCMA = DESMAF_SS - A_DES - FN818(PERLOAD_ISC) *BP/29.875*FN059(ACT)

where: FN818(PERLOAD_ISC) is a function of PERLOAD_ISC and represents flow leaking into the manifold.

Next, in step 328, a desired throttle position (ETCPOS) is calculated as a function of the amount of air desired around throttle plate 62 (DEETCMA). The routine then calculates the desired air assist injector airflow equivalent at standard temperature and pressure (AAI_DES_FST) as shown in step 328. Next, this value is converted to a duty cycle (AAIDTY) in step 332 as a function of the bypass valve versus duty cycle and pressure ratio. More specifically, signal AAIDTY is generated as a function of signals AAI_DES_FST and signal PERLOAD_ISC. Signal PERLOAD_ISC was generated as previously described with reference to step 212. Finally, in step 334, AAIDTY is clipped to a maximum value of one because it is improper to request a duty cycle greater than one hundred percent.

Referring now to Figure 4, the subroutine for generating correction signal TR_DSDRPM to correct open loop desired air flow signal DESMAF_PRE and the corresponding initial throttle position of bypass throttle valve 96 is now described. An absolute limit of ignition timing (signal SPK_ABS_LIM) is first selected in step 402 as the minimum of: ignition timing at maximum engine torque MBT (signal SPK_MBT), ignition timing associated with borderline knock (signal SPK_BDL); and ignition timing associated with engine misfire (signal SPK_MF).

The above generated spark absolute limit (SPK_ABS_LIM) is then converted to torque ratio TR_ABS by conversion function FN766 during step 406. TR_ABS is the ratio of indicated torque at SPK_ABS_LIM to the indicated torque at SPK_MBT.In this particular example, conversion function FN766 is a table of engine output torque as a function of ignition timing.

Ignition signal SA_COLD, which is the ignition timing retard during engine startup, is converted in step 408 to torque ratio TR_FLEX by function FN766. Torque ratio TR_FLEX is the flexible torque ratio limit which may be exceeded if required to maintain engine idle speed. Reserved torque ratio TR_RES_BASE, which could correspond to a reserve in ignition timing to maintain a desired range of authority for engine idle speed control via ignition timing, is then generated in step 410 by taking the difference between torque ratio TR_ABS and torque ratio TR_FELX.

During step 412, the correction value associated with the torque ratio at desired engine speed (TR_DSDRPM) is generated by taking the difference between absolute torque ratio TR_ABS and reserve torque ratio TR_RES.

Referring now to Figure 5, the subroutine executed by controller 12 for controlling total engine airflow during non-idle conditions are now described. During step 510, a driver demand signal (DD) is obtained from, for example, a position sensor measuring a driver pedal mounted in the engine compartment. As would be obvious to one of ordinary skill in the art and in view of this disclosure, many other methods may be used to infer a driver demand signal. In step 512, desired mass air flow (DESMAF_SS) is calculated as a function of the driver demand signal (DD). As is obvious to one of ordinary skill in the art, DESMAF_SS may also be a function of many other signals, such as engine speed, engine torque, desired engine torque, and vehicle speed. Finally, in step 514, the air assist injector maximization routine is called to distribute the required airflow between electronic throttle controller 63 and bypass valve 97.

As previously described herein, the air assist maximization routine will maintain the air flowing through air assist injectors at a maximum value while still maintaining a necessary range of authority of the electronic throttle controller to reject disturbances and maintain the desired idle speed or engine torque. By doing this, optimum

fuel atomization may be obtained resulting in minimal emissions and reduced engine speed fluctuations.

Referring now to Figures 6 and 7, and in particular to Figure 6, a plot of an example of operation according to the present invention shows the total desired airflow through the engine to maintain a constant engine speed during idle conditions (solid line). A dotted line of this example shows the maximum possible airflow through the air assist injectors (AAI_MAX_FLW), which in this example is equal to the desired airflow through the air assist injectors (A_DES). At time t1, an accessory load for example is applied to the engine, which causes the engine to require more airflow. At time t2, the accessory load is removed. In this example, the engine operating condition, such as, for example, engine coolant temperature, is used to determine that the minimum required airflow, shown by the dash-dot line, will never be below the maximum possible airflow through the air assist injectors (AAI_MAX_FLW). In other words, when this minimum required airflow is greater than or equal to the maximum possible airflow through the air assist injectors (AAI_MAX_FLW), the airflow through the air assist injects can be set at the maximum value. Thus, in this example, the desired airflow through the air assist injectors (A_DES) is set to this maximum value and throttle controller 63 will have a range of authority greater than the difference between the total desired airflow and the desired airflow through the air assist injectors as shown in Figure 6.

Continuing with Figure 7, which shows an example of a situation where the maximum possible airflow through the air assist injectors (AAI_MAX_FLW) is greater than the minimum required airflow for this operating condition. In this example, at time t3 an engine accessory load is removed and then reapplied at time t4. Thus, in this example, the desired airflow through the air assist injectors (A_DES) must be set lower than this minimum required airflow as shown in Figure 7. By doing this, a situation where the

total required airflow drops below the airflow through the air assist injectors is avoided. This further avoids a situation where throttle controller 63 must completely close throttle plate 62 and rely on bypass valve 97 to maintain engine idle speed by reducing flow through the air assist injectors.

The two examples in Figures 6 and 7 show that, by using a priori knowledge of the minimum required airflow versus engine operating conditions, it is possible to control the air through the air assist injectors such that throttle plate 62 will never be more closed that a predetermined value. This allow throttle plate 62 to maintain primary control at all times throughout all operating conditions.

CLAIMS

1. An air control method for an internal combustion engine, the engine having a first airflow control valve (58,62,63,64 and air assist injectors (66), said method comprising:

calculating a minimum total required airflow based on engine operating conditions;

controlling the first airflow control valve (58,62,63,64) to regulate a first quantity of airflow through the engine; and

controlling a second quantity of airflow through the air assist injectors (66) such that said first quantity of airflow is greater than a predetermined value with said predetermined value being defined as a difference between said total required airflow and said first quantity, thereby allowing said first airflow control valve to maintain primary control of the engine.

2. A method as claimed in Claim 1, wherein said step of controlling the first airflow control valve further comprises the step of controlling the first airflow control valve to regulate said first quantity of airflow in response to an engine speed error signal.

3. A method as claimed in Claim 1, wherein said step of controlling the first airflow control valve further comprises the step of controlling the first airflow control valve to regulate said first quantity of airflow in response to a desired engine torque signal.

4. A method as claimed in Claim 1, wherein said step of controlling the first airflow control valve further comprises the step of controlling the first airflow control valve to regulate said first quantity of airflow in response to a desired total airflow signal.

5. A method as claimed in Claim 1, further comprising the step of adjusting said predetermined value in response to engine operating conditions.

6. A method as claimed in Claim 1, further comprising the step of adjusting said predetermined value in response to engine operating temperature.

7. An air control method for an internal combustion engine, the engine having a sensor for sensing a speed of the engine, a first airflow control valve and air assist injectors coupled between the engine and a second airflow control valve, said method comprising:

calculating a minimum total required airflow based on engine operating conditions;

controlling the first airflow control valve to regulate a first quantity of airflow through the engine;

controlling the second quantity of airflow through the air assist injectors such that the first quantity of airflow is not less than a predetermined value and a sum of said first quantity and said second quantity is equal to said total required airflow, thereby allowing the first airflow control valve to maintain primary control of the engine.

8. A method as claimed in Claim 7, further comprising the step of adjusting said predetermined value in response to engine operating conditions.

9. A method as claimed in Claim 7, further comprising the step of adjusting said predetermined value in response to engine operating temperature.

10. A control system for an internal combustion engine having air assist injectors (66) comprising:

a first airflow control valve (58,62,63,64) for controlling a first quantity of airflow entering the engine;

a second airflow control valve (97) for controlling a second quantity of airflow passing through the air assist injectors (66) and then entering the engine;

a controller (12) for controlling said first airflow control valve to regulate a total quantity of airflow through the engine, calculating a range of authority necessary for said first airflow control valve to maintain idle speed control of the engine, and controlling said second airflow control valve to allow said second quantity of airflow passing through the air assist injectors (66) to be a maximum, but less than a difference between said total quantity of airflow and said range of authority.

11. A system as claimed in Claim 10, wherein said controller further calculates said range of authority as a function of engine operating conditions.

12. A system as claimed in Claim 10, wherein said controller further calculates said range of authority as a function of engine operating temperature.

13. A system as claimed in Claim 10, wherein said controller further controls said first airflow control valve to regulate said first quantity of airflow in response to an engine speed error signal.

14. A system as claimed in Claim 10, wherein said controller further controls said first airflow control valve to regulate said first quantity of airflow in response to a desired engine torque signal.

15. A system as claimed in Claim 10, wherein said controller further controls said first airflow control valve

to regulate said first quantity of airflow in response to a desired total airflow signal.

16. An air control method for an internal combustion engine substantially as hereinbefore described with reference to the accompanying drawings.

17. An air control system for an internal combustion engine substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Application No:	GB 9909655.4	**Examiner:**	Michael Prescott
Claims searched:	1, 7, 10	**Date of search:**	9 August 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G3N (NGBXE, NGBXX, NGE2); G3R (RBN29)

Int Cl (Ed.6): F02D 7/02; F02M 69/08

Other: Online databases: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	US 5730110	(Chrysler Corporation) whole document	1, 7, 10
X	US 5421311	(Wataya, S - Mitsubishi) whole document	1, 7, 10
X	US 5211148	(Furuya, J et al - Japanese Electronic Control Systems) see embodiments of Fig 4, 7 and 8	1, 7, 10

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.